

**ECE445**  
**Fall 2026**

# **Adaptive Light-Filtering Glasses**

**Team 7**

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# 1. Introduction

## 1.1. Problem and Solution

Photosensitive epilepsy (PSE) is a form of epilepsy in which seizures can be triggered by visual stimuli such as flashing lights, repetitive patterns, and rapid changes in color or brightness. The likelihood of provoking a photosensitive response depends on several characteristics of the stimulus, including its frequency, intensity, color, and percentage of the visual field occupied [1]. Potentially hazardous visual stimuli can occur unexpectedly in everyday environments through artificial lighting, electronic displays, video games, and other visual media. This unpredictability creates a need for a wearable system capable of identifying potentially hazardous flickering light and reducing the user's exposure without unnecessarily obstructing vision during normal lighting conditions. Existing approaches to photosensitivity primarily rely on avoiding known triggers or using passive optical filtering, motivating the development of a system that can instead detect and respond to changing visual conditions in real time [1], [2].

Our solution is a pair of adaptive light-filtering glasses that continuously monitors incoming light and dynamically controls lens attenuation according to the detected flicker risk. Two front-facing photodiodes with different fields of view measure directional and ambient light, while a microcontroller processes these signals to determine the frequency and magnitude of detected flicker. When a potentially hazardous flicker is identified, the system increases the attenuation of electronically controlled LCD light valves incorporated into the lenses [6]. A third photodiode measures the remaining light after attenuation, forming a closed feedback loop that allows the system to continuously adjust the lenses according to the measured exposure. The primary improvement of this design over passive filtering is its ability to selectively respond to detected hazardous flicker rather than continuously attenuating incoming light. By combining real-time flicker detection, electronically controlled lens attenuation, and optical feedback in a wearable system, the proposed design aims to provide increased attenuation when necessary while preserving greater visibility under normal lighting conditions.

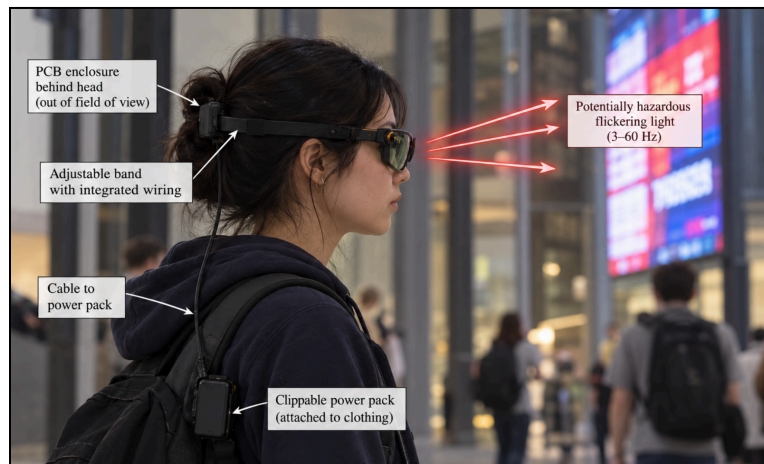
## 1.2 Visual Aid

Figures 1-4 illustrate the proposed adaptive light-filtering glasses and how the system will be worn and used. The user wears the glasses using an adjustable band containing wiring between the sensors, light-valve lenses, and a PCB enclosure positioned behind the user's head. Placing the PCB enclosure at the rear of the band keeps the electronics outside the user's field of view while distributing their weight away from the front of the glasses. Two front-facing photodiodes monitor incoming environmental light, while a third photodiode provides optical feedback after attenuation. The light-valve lenses are positioned in front of the user's eyes and dynamically adjust their attenuation when potentially hazardous flicker is detected.

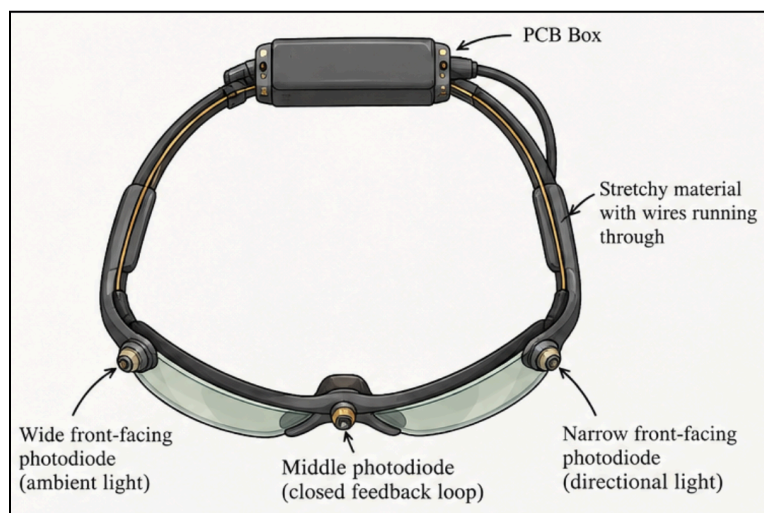
A cable from the PCB enclosure connects the glasses to a rechargeable power pack that can be clipped to the user's clothing, reducing the amount of weight that must be supported by the user's head. The base design operates independently and does not require communication with a phone, computer, or other external system. As a stretch goal, an emergency-response subsystem may be incorporated in which an

IMU monitors for abnormal movement associated with possible seizure activity and communicates with an external device to alert an emergency contact.

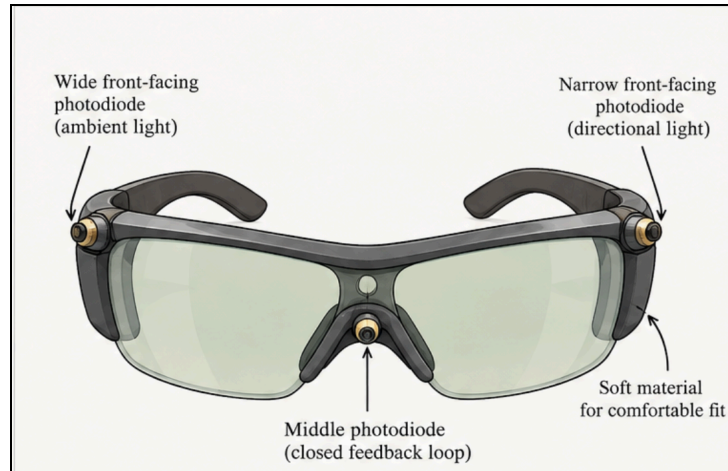
The images (Figure 1 to 5) were created using AI assistance. They are based off of our previous hand-drawn images of the proposed solution.



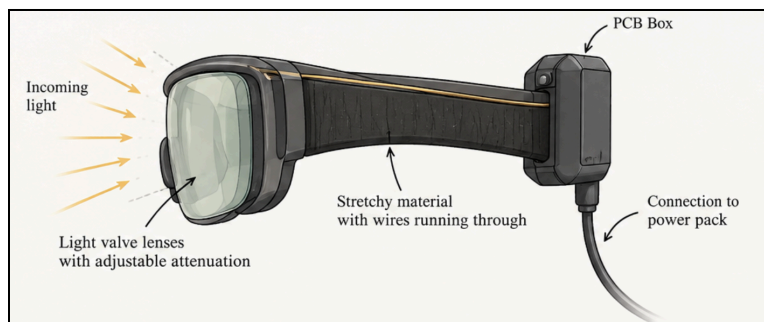
**Figure 1:** User wearing Adaptive Light-Filtering Glasses (System in Context)



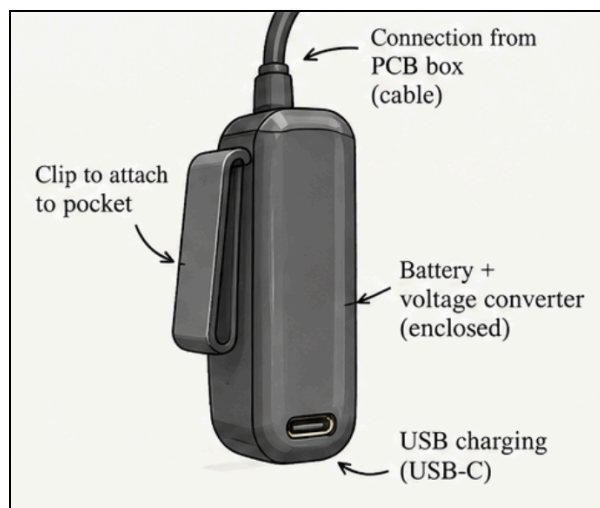
**Figure 2:** Top Down View of Glasses



**Figure 3: Front Facing View of Glasses**



**Figure 4: Side View of Glasses**



**Figure 5: Clippable Power Pack**

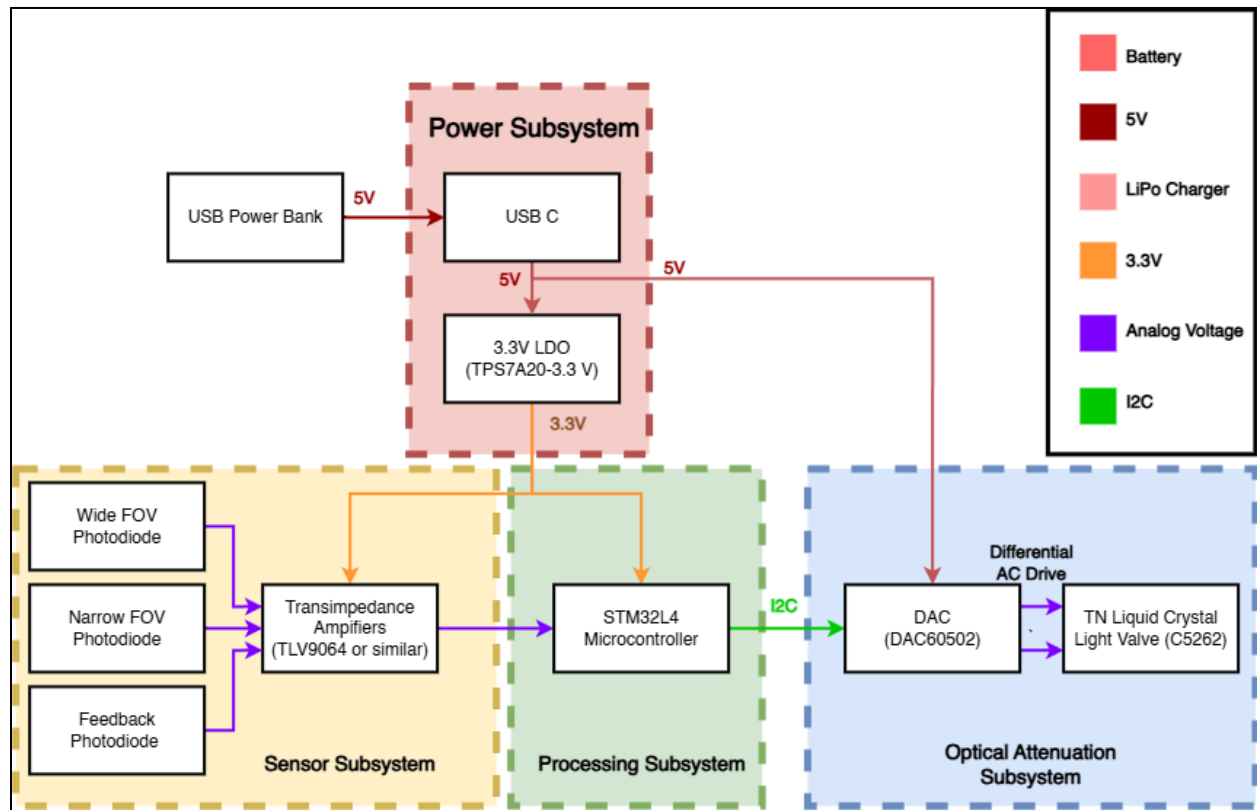
### 1.3 High Level Requirements List

The following high-level requirements define the objective characteristics that the system must exhibit in order to successfully address the problem:

- The system must detect hazardous flickering light within the **3–60 Hz** frequency range with a detection accuracy of at least **80%**, while maintaining a false-positive rate below **10%** for non-hazardous variations in light intensity.
- The system must detect a hazardous flicker and activate the optical attenuation system within **0.5 seconds** of the onset of the hazardous input.
- The system must operate continuously for at least **8 hours** on a single full battery charge under normal operating conditions.

## 2. Design

### 2.1 Block Diagram

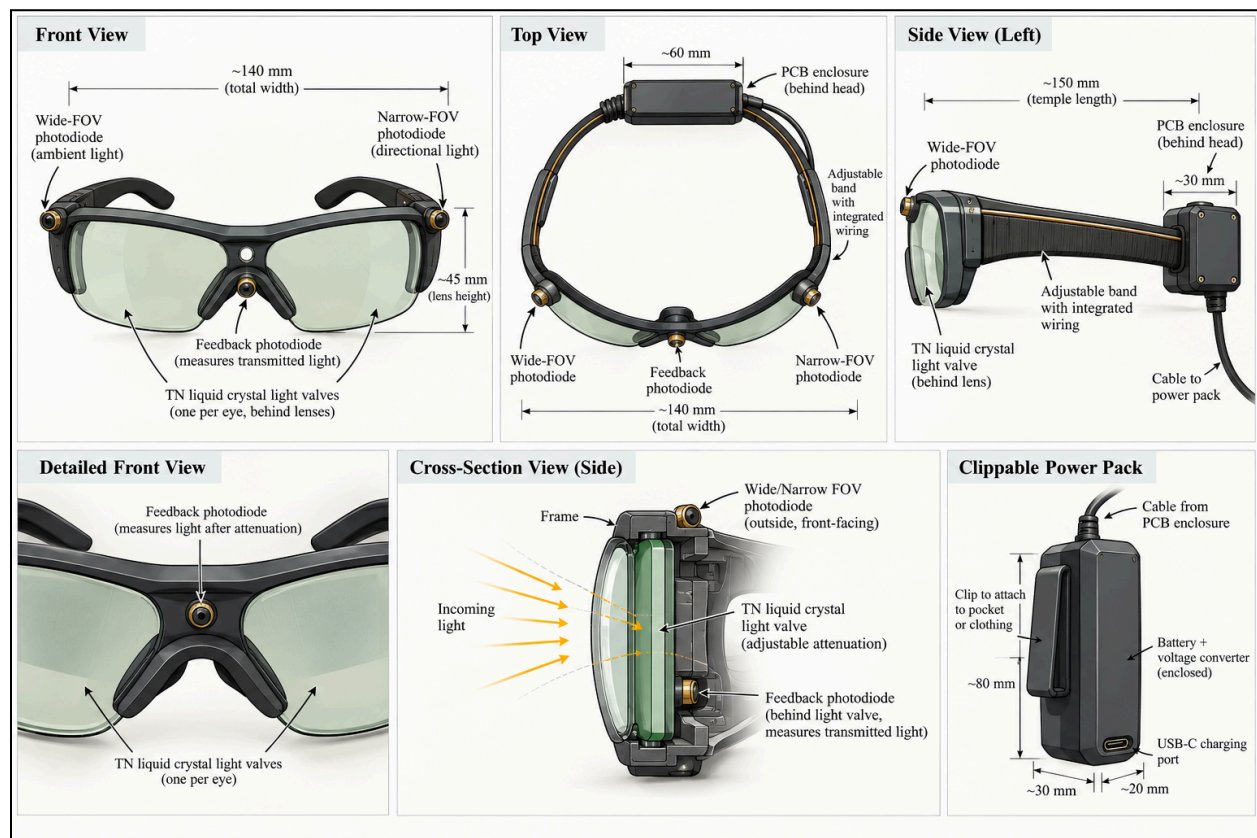


*Figure 6: Block Diagram of the Proposed Solution*

The proposed system consists of four primary subsystems: the sensor, processing, optical attenuation, and power subsystems, as shown in Figure 6. The sensor subsystem uses three photodiodes and transimpedance amplifiers to measure incoming light and convert the photodiode currents into voltage signals that can be processed by the microcontroller. The processing subsystem analyzes these signals to determine the frequency and magnitude of incoming flicker and determines the required level of optical attenuation. The optical attenuation subsystem uses a DAC and TN liquid crystal light valve to adjust the amount of light transmitted to the user based on commands from the processing subsystem. The power subsystem supplies the required 3.3 V and 5 V power rails to the other subsystems and provides rechargeable battery operation for the device. Together, these subsystems form a closed-loop system in which the feedback photodiode measures the light transmitted through the light valve, allowing the processing subsystem to continuously adjust the attenuation level. This feedback path occurs optically rather than electrically and is therefore not represented by an electrical connection in the block diagram.

## 2.2 Physical Design

The physical design of the system consists of a wearable glasses assembly connected to an external clippable power pack, as shown in Figures 7. Figure 7 illustrates the overall physical arrangement of the system, including the placement of the wide-FOV and narrow-FOV photodiodes at the front of the glasses, the TN liquid crystal light valves in front of the user's eyes, the PCB enclosure at the rear of the adjustable headband, and the external power pack connected by cable. The wide-FOV and narrow-FOV photodiodes are positioned to measure ambient and directional incident light, respectively, while the feedback photodiode is positioned behind the optical attenuation plane to measure light after it has passed through the light valve. The dimensions shown represent the current mechanical design targets and will be refined as the final PCB, enclosure, light valves, and mounting hardware are fabricated and assembled.



**Figure 7:** Physical Layout of Adaptive Light-Filtering Glasses

## 2.3 Functional Overview & Block Diagram Requirements

### 2.3.1 Power Subsystem

The Power Subsystem is responsible for supplying power to all electronic components in the glasses. The system is powered by an external USB-C power bank that supplies a 5 V input. The 5 V supply powers the optical attenuation subsystem directly and is regulated down to 3.3 V using an onboard LDO to power the sensor and processing subsystems.

Using an external power bank allows the system to remain portable while eliminating the need for an onboard battery and charging circuit. The power subsystem must provide stable 3.3 V and 5 V power rails under the maximum expected system load and provide sufficient energy for at least 8 hours of continuous operation. All subsystems share a common ground to provide a consistent reference for power and signal transmission.

| Requirements                                                                                                                                                                       | Verification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The power subsystem must provide a voltage between 3.135 V and 3.465 V (3.3 V $\pm$ 5%) to the sensor and processing subsystems while all subsystems are operating simultaneously. | <p><b>Tools:</b> Oscilloscope and USB-C power bank.</p> <p><b>Procedure:</b> Connect the USB-C power bank to the complete system. Operate the sensor, processing, and optical attenuation subsystems simultaneously. Monitor the 3.3 V rail with the oscilloscope and record the minimum, maximum, and average voltages.</p> <p><b>Successful Verification Result:</b> The measured voltage remains within the 3.3 V <math>\pm</math>5% range during operation, with the minimum voltage never dropping below 3.135 V and the maximum voltage never exceeding 3.465 V.</p> |
| The power subsystem must provide a 5 V $\pm$ 5% supply to the optical attenuation subsystem while the complete system is operating.                                                | <p><b>Tools:</b> Oscilloscope and USB-C power bank.</p> <p><b>Procedure:</b> Connect the USB-C power bank to the complete system. Operate the sensor, processing, and optical attenuation subsystems simultaneously. Monitor the 5 V rail with the oscilloscope and record the minimum, maximum, and average voltages.</p> <p><b>Successful Verification Result:</b> The measured voltage remains within the 5 V <math>\pm</math>5% range during operation, with the minimum voltage never dropping below 4.75 V and the maximum voltage never exceeding 5.25 V.</p>       |
| The power subsystem must provide sufficient energy for at least 8 hours of continuous operation                                                                                    | <p><b>Tools:</b> Timer and USB-C power bank.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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**Procedure:** Connect a fully charged USB-C power bank to the complete system. Operate all subsystems under normal operating conditions and start the timer. Record the total amount of time for which the system remains operational.

**Successful Verification Result:** The complete system remains operational for at least 8 hours from a fully charged USB-C power bank. Record the total operating time.

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***Table 1:** Requirements and Verification Table for the Power Subsystem*

### **2.3.2 Sensor Subsystem**

The Sensor Subsystem is responsible for detecting and measuring variations in light intensity in the user's field of view. It consists of three photodiodes: a wide field-of-view (FOV) photodiode, a narrow FOV photodiode, and a feedback photodiode. Each photodiode is connected to a low-gain transimpedance amplifier (TIA) based on the TLV9064 [9]. The TIAs convert the photodiode currents into analog voltage signals. A relatively low transimpedance gain is used to provide sufficient dynamic range and prevent the TIA outputs from saturating under the expected range of ambient lighting conditions.

The wide FOV photodiode measures light over a broad region surrounding the user, while the narrow FOV photodiode measures light primarily in the user's forward field of view. These two channels provide measurements of the surrounding and forward-facing lighting conditions that can be used by the Processing Subsystem for flicker detection. The feedback photodiode is positioned behind the optical valve [Section 2.2.4] and measures the received light intensity after attenuation. This measurement allows the Processing Subsystem to evaluate the effect of the optical attenuation and provide feedback to the control system.

The output of each TIA is passed through a second active filtering and amplification stage before being provided to the Processing Subsystem. This stage provides additional voltage gain to the photodiode signal while acting as a low-pass filter to attenuate high-frequency noise and interference before ADC sampling. The analog filter is not intended to isolate only the final 3–60 Hz flicker detection band. Instead, it limits the bandwidth of the analog signal and reduces high-frequency components that could contribute to aliasing or noise. Additional filtering and isolation of the 3–60 Hz frequency range are performed digitally by the Processing Subsystem.

The Sensor Subsystem receives 3.3 V and a common ground reference from the Power Subsystem. It provides three conditioned analog voltage signals, one from each photodiode channel, to the Processing Subsystem for ADC sampling and subsequent flicker detection and attenuation control.

| Requirements                                                                                                                                                                                                                                                                                                                                                                                         | Verification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>The Sensor Subsystem must produce analog outputs within the 0–3.3 V ADC input range for each of the three photodiode channels with a range of intensities approximately between 10 and 1000 lux, which corresponds to dim indoors conditions to soft overcast conditions. The output must not remain within 50 mV of either supply rail during the defined flicker-detection test conditions.</p> | <p><b>Tools:</b> Oscilloscope, test light source, and completed Sensor Subsystem.</p> <p><b>Procedure:</b> Connect the oscilloscope to the conditioned analog output of each sensor channel. Illuminate the corresponding photodiode using the minimum and maximum illumination conditions that will be used during system verification. Record the minimum and maximum output voltage of each channel. Repeat for the wide-FOV, narrow-FOV, and feedback channels.</p> <p><b>Successful Verification Result:</b> Each sensor output remains between 0.05 V and 3.25 V throughout the defined flicker-detection test conditions. Record the minimum and maximum voltage for each channel in a table.</p>                                                                                                                                                                        |
| <p>The Sensor Subsystem must preserve detectable periodic variations in incident light throughout the complete 3–60 Hz flicker-detection range. For sinusoidal optical inputs at 3 Hz, 10 Hz, 30 Hz, and 60 Hz, the dominant frequency measured from the conditioned sensor output must be within <math>\pm 1</math> Hz of the applied flicker frequency.</p>                                        | <p><b>Tools:</b> Controllable LED light source, signal/function generator or microcontroller capable of modulating the LED, oscilloscope, and Sensor Subsystem.</p> <p><b>Procedure:</b> Position the light source at a fixed distance from the photodiode. Modulate the light source sequentially at 3, 10, 30, and 60 Hz. Connect the oscilloscope to the conditioned sensor output and record the waveform for each input frequency. Use the oscilloscope's frequency measurement or recorded waveform to determine the dominant measured frequency. Repeat for the wide-FOV and narrow-FOV channels.</p> <p><b>Successful Verification Result:</b> The measured frequency is within <math>\pm 1</math> Hz of the commanded optical flicker frequency at every tested frequency. Record commanded and measured frequencies in a table and save representative waveforms.</p> |
| <p>The analog conditioning circuitry must attenuate signals above the intended sensor bandwidth such that the output amplitude at 10kHz is at least 40dB below the output amplitude at 60 Hz for equal-amplitude input signals.</p>                                                                                                                                                                  | <p><b>Tools:</b> Function generator and oscilloscope.</p> <p><b>Procedure:</b> Inject an electrical sinusoidal test signal into the analog conditioning stage at an amplitude that does not cause saturation. Measure the output amplitude at 60 Hz and at the selected high-frequency test frequency. Calculate <math>20\log_{10}(V_{high}/V_{60})</math>.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

|                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                  | <p><b>Successful Verification Result:</b> The measured high-frequency attenuation meets or exceeds the calculated design requirement. Record the input frequency, input amplitude, output amplitude, and calculated attenuation in a table.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <p>The feedback photodiode channel must detect a change in transmitted light caused by a change in the commanded state of the optical light valve, with the measured signal changing consistently in the expected direction for at least three commanded attenuation states.</p> | <p><b>Tools:</b> Constant light source, oscilloscope, completed feedback photodiode channel, and Optical Attenuation Subsystem.</p> <p><b>Procedure:</b> Position a constant light source in front of the light valve and do not change its position or intensity during the test. Record the steady-state feedback-channel output at minimum attenuation. Command an intermediate attenuation state and record the output. Command maximum attenuation and record the output. Repeat the sequence three times.</p> <p><b>Successful Verification Result:</b> The feedback signal changes monotonically in the expected direction from minimum to intermediate to maximum attenuation in all three trials. Present the measured feedback voltage for each attenuation state in a table.</p> |

*Table 2: Requirements and Verification Table for the Sensor Subsystem*

### 2.3.3 Processing Subsystem

The Processing Subsystem is responsible for sampling and analyzing the signals generated by the Sensor Subsystem, determining the level of flicker hazard, and commanding the Optical Attenuation Subsystem when intervention is required. It consists of an STM32L412 [12] microcontroller that samples the three conditioned analog signals from the Sensor Subsystem using its onboard 12-bit ADC. The sensor signals are sampled at approximately 100 kHz to increase the Nyquist frequency and reduce the burden placed on the analog anti-aliasing filters in the Sensor Subsystem.

The STM32L412's ADC hardware oversampling functionality is used to acquire multiple ADC conversions and accumulate and average the results in hardware. This allows the system to take advantage of the high sampling rate to reduce the contribution of random noise without requiring the processor to individually average every ADC conversion in software. The resulting samples are then digitally filtered to remove frequency components outside the range required for flicker analysis and reduced to a lower effective sampling rate for subsequent processing.

The processed signals are analyzed to determine the presence and intensity of flicker within the target 3–60 Hz frequency range. Based on this analysis, the microcontroller calculates a flicker hazard level and determines the amount of optical attenuation required.

The Processing Subsystem acts as the decision-making component of the overall system. When hazardous flicker is detected, the microcontroller commands the Optical Attenuation Subsystem by sending the required attenuation level to the DACs through I2C. The Processing Subsystem also samples the output of the feedback photodiode located behind the optical valve. This measurement is compared with the desired attenuation level, and a PI controller is used to adjust the commanded attenuation in response to differences between the desired and measured attenuation.

The Processing Subsystem receives a regulated 3.3 V supply and common ground reference from the Power Subsystem. It receives three conditioned analog voltage signals from the Sensor Subsystem through the microcontroller ADC inputs. It interfaces with the Optical Attenuation Subsystem through I2C communication with the DACs, which generate the signals required to control the TN optical valve.

| Requirements                                                                                                                                                                                                                                | Verification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The Processing Subsystem must sample each sensor channel at an ADC conversion rate of approximately 100 kHz and use the STM32 ADC hardware oversampling functionality to average multiple conversions before subsequent digital processing. | <p><b>Tools:</b> Oscilloscope and STM32 development/debugging software.</p> <p><b>Procedure:</b> Configure the ADC with the final sampling and hardware oversampling settings. Apply a known periodic electrical signal to an ADC input and acquire a fixed number of processed samples. Measure the acquisition interval and verify the configured ADC conversion and oversampling settings.</p> <p><b>Successful Verification Result:</b> The measured ADC conversion rate is within <math>\pm 5\%</math> of 100 kHz, and the configured hardware oversampling produces the expected number of averaged output samples. Record the configured oversampling ratio, measured acquisition interval, and calculated sampling rate.</p> |
| The Processing Subsystem must correctly identify periodic flicker frequencies throughout the target 3–60 Hz range with a frequency measurement error of no more than $\pm 5\%$ .                                                            | <p><b>Tools:</b> Function generator, oscilloscope, and STM32 development/debugging software.</p> <p><b>Procedure:</b> Apply sinusoidal signals representing sensor outputs at several known frequencies throughout the target range, including 3 Hz and 60 Hz, to the ADC input. Record the frequency determined by the Processing Subsystem for each input.</p> <p><b>Successful Verification Result:</b> The Processing Subsystem identifies each applied flicker frequency with an error no greater than <math>\pm 5\%</math> of the applied frequency. Record the applied and detected frequencies and calculated percent error in a table.</p>                                                                                  |

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The Processing Subsystem must distinguish signals within the 3–60 Hz flicker detection band from signals outside the detection band.

**Tools:** Function generator and STM32 development/debugging software.

**Procedure:** Apply equal-amplitude sinusoidal signals at frequencies below, within, and above the 3–60 Hz detection band. Record the digitally processed signal magnitude or hazard metric produced for each test frequency.

**Successful Verification Result:** Signals within the 3–60 Hz detection band are retained for flicker analysis, while signals outside the detection band are attenuated according to the calculated digital-filter specification. Record the input frequency and corresponding processed output magnitude in a table.

---

The Processing Subsystem must detect a hazardous flicker condition and issue the corresponding attenuation command within 0.5 s of the hazardous flicker appearing at its sensor input.

**Tools:** Function generator, oscilloscope, and logic analyzer.

**Procedure:** Apply a signal representing a hazardous flicker condition to the sensor input while monitoring the applied signal and the Processing Subsystem's output command to the DAC. Measure the elapsed time between the onset of the hazardous input and transmission of the attenuation command. Repeat the measurement at several frequencies within the 3–60 Hz range.

**Successful Verification Result:** The attenuation command is issued within 0.5 s of the onset of the hazardous flicker condition for every tested frequency. Record the measured response time for each trial.

---

The Processing Subsystem must use the feedback photodiode measurement to adjust the attenuation command when the measured attenuation differs from the commanded attenuation.

**Tools:** Adjustable light source, oscilloscope, and STM32 development/debugging software.

**Procedure:** Operate the closed-loop attenuation controller under a constant light source and command a fixed attenuation level. Introduce a change in the feedback photodiode signal representing a difference between the desired and measured attenuation. Record the feedback measurement and resulting controller output.

**Successful Verification Result:** The PI controller changes the attenuation command in the direction required to reduce the error between the desired and measured attenuation. Record the desired

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attenuation, feedback measurement, error, and resulting controller output.

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**Table 3:** *Requirements and Verification Table for the Processing Subsystem*

### 2.3.4 Optical Attenuation Subsystem

The Optical Attenuation Subsystem is responsible for controlling the amount of light transmitted through the glasses in response to commands from the Processing Subsystem. It consists of a TN liquid-crystal optical valve and its associated drive circuitry. Changing the voltage applied across the optical valve changes its optical transmission, allowing the system to attenuate hazardous flickering light.

The attenuation level is controlled using DACs commanded by the STM32L412 through I2C. The DACs convert the digital attenuation commands into analog voltage levels used to generate a differential AC drive signal across the TN optical valve. An alternating signal is used to avoid maintaining a DC bias across the liquid-crystal element, while the magnitude of the applied differential voltage controls the resulting attenuation.

The subsystem receives 5 V and a common ground reference from the Power Subsystem and control commands from the Processing Subsystem. A feedback photodiode positioned behind the optical valve measures the transmitted light and provides this measurement to the Processing Subsystem, allowing the attenuation level to be adjusted through closed-loop control.

| Requirements                                                                                                                                                                                                                                              | Verification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The optical attenuation subsystem must generate a differential AC waveform across each TN light valve with an adjustable magnitude from 0 V to at least 4.75 V peak and an average DC component within $\pm 50$ mV over a 10-second measurement interval. | <p><b>Tools:</b> Oscilloscope with two voltage probes and math/subtraction functionality.</p> <p><b>Procedure:</b> Connect oscilloscope Channel 1 to DAC output A and Channel 2 to DAC output B with respect to common ground. Connect the light valve normally. Command minimum, 25%, 50%, 75%, and maximum drive levels from the processing subsystem. Record <math>V_A</math>, <math>V_B</math>, and the calculated differential waveform <math>V_A - V_B</math> for each command. At maximum drive, measure the positive and negative differential amplitudes and the mean voltage over a 10-second interval.</p> <p><b>Successful Verification Result:</b> The differential drive magnitude is adjustable from approximately 0 V through at least 4.75 V peak, and the measured mean differential voltage remains between <math>-50</math> mV and <math>+50</math> mV. Results will be recorded as oscilloscope screenshots and a table of commanded versus measured drive voltages.</p> |

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The optical attenuation subsystem must produce a measurable and repeatable reduction in transmitted light as the commanded attenuation level is increased, with maximum attenuation reducing the feedback-photodiode measured light level by at least 10% relative to the minimum-attenuation state under constant illumination.

**Tools:** Constant light source, feedback photodiode/sensor circuitry, oscilloscope or MCU data logger.

**Procedure:** Position the light source at a fixed distance and orientation relative to the light valve and keep its intensity constant. Record the feedback-photodiode output at minimum attenuation. Command 25%, 50%, 75%, and maximum attenuation and record the steady-state feedback signal for each level. Repeat the complete measurement three times. Normalize each measurement to the minimum-attenuation measurement.

**Successful Verification Result:** Increasing the commanded attenuation produces a repeatable decrease in transmitted-light measurement, and maximum attenuation reduces the measured transmitted-light level by at least 10%. Results will be presented as a plot of normalized transmitted light versus commanded attenuation level.

---

The optical attenuation subsystem must reach and remain within  $\pm 5\%$  of its final steady-state transmitted-light measurement within 500 ms after receiving an attenuation command from the processing subsystem.

**Tools:** Oscilloscope, feedback photodiode, and microcontroller test/debug output.

**Procedure:** Configure a microcontroller GPIO pin to toggle simultaneously with transmission of an attenuation command. Connect oscilloscope Channel 1 to the GPIO signal and Channel 2 to the feedback-photodiode output. Command a transition from minimum attenuation to maximum attenuation and measure the elapsed time from the GPIO transition to the point at which the feedback signal enters and remains within  $\pm 5\%$  of its final steady-state value. Repeat the test at least 10 times.

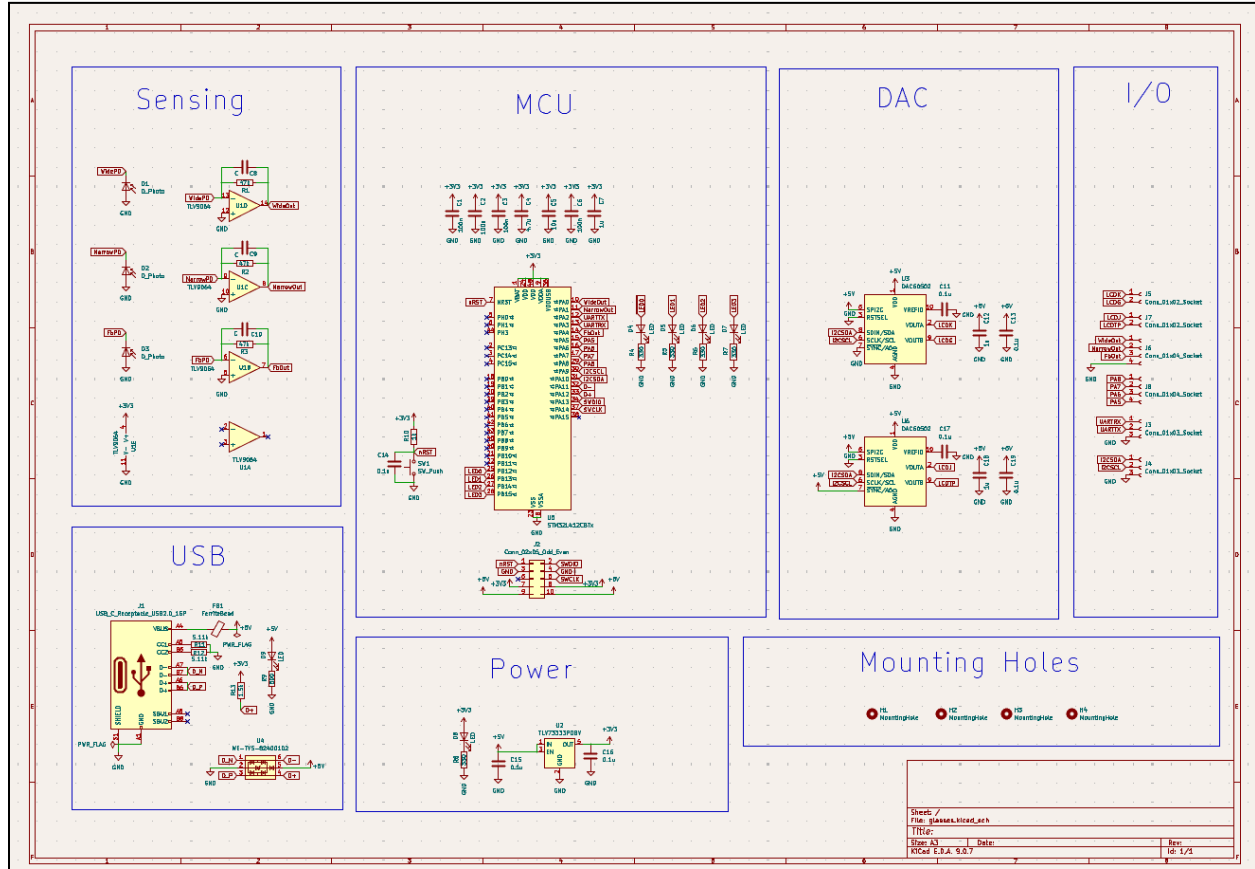
**Successful Verification Result:** Each measured transition settles within  $\pm 5\%$  of its final transmitted-light value within 500 ms of the command. Record all measured response times in a table and report the maximum measured response time.

---

**Table 4:** Requirements and Verification Table for Optical Attenuation Subsystem

## 2.4 Hardware Design

The hardware design integrates the sensing, processing, optical attenuation, power, and external interface circuitry onto a single PCB. Figure 9 shows the complete system schematic. The PCB receives a 5 V supply through USB-C, regulates this supply to 3.3 V for the sensing and processing circuitry, acquires three photodiode signals through analog front-end circuits, processes the signals using the STM32 microcontroller, and controls the TN liquid crystal light valves through DAC output channels. The following sections describe and justify the major circuit-level design decisions.



**Figure 9:** Complete PCB Schematic for the Adaptive Light-Filtering Glasses

### 2.4.1. Photodiode Analog Front End

Each BPW34 photodiode is connected to a transimpedance amplifier (TIA) implemented using one channel of the TLV9064 operational amplifier. The TIA converts the photocurrent generated by each photodiode into a voltage suitable for further conditioning and sampling by the microcontroller ADC. Three equivalent channels are implemented for the wide-FOV, narrow-FOV, and feedback photodiodes. The transimpedance gain is primarily determined by the feedback resistance  $R_F$ :

$$V_{TIA} = V_{REF} - I_{PD} R_F$$

with

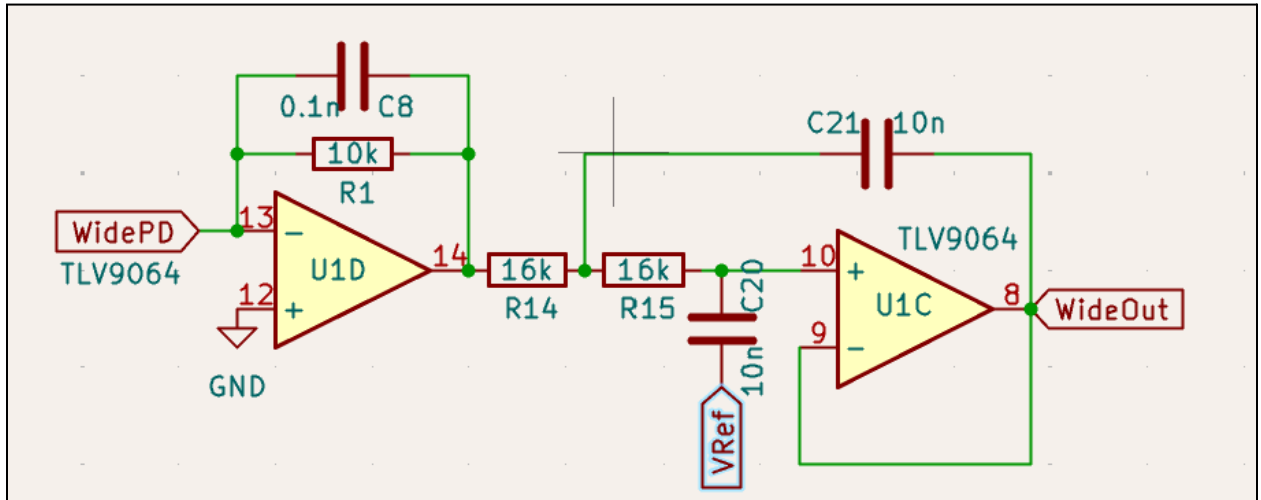
$$R_F = 10k\Omega.$$

The 10 k $\Omega$  feedback resistance was selected to provide measurable output variation while maintaining sufficient voltage headroom to reduce the probability of saturation under bright ambient illumination. A 0.1nF feedback capacitor is placed in parallel with the feedback resistor to limit the TIA bandwidth and improve amplifier stability. The TIA is referenced to  $V_{REF}$  to bias its output within the 0–3.3 V ADC input range.

The output of each TIA is passed through an active low-pass filter implemented using another TLV9064 channel. The filter uses  $R_1 = R_2 = 16k\Omega$  and  $C_1 = C_2 = 10nF$ , resulting in a characteristic frequency of approximately

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \approx 995Hz.$$

This cutoff is well above the 3–60 Hz flicker detection band, allowing the frequencies of interest to pass with minimal attenuation while reducing higher-frequency noise before ADC sampling. Additional filtering is performed digitally by the Processing Subsystem. The TLV9064 was selected for its rail-to-rail input/output operation and compatibility with the 3.3 V analog supply [9].



**Figure 10:** Photodiode and TIA Circuit [SENSING BOX]

#### 2.4.2. Microcontroller and ADC Interface:

The STM32L412 microcontroller serves as the central processing element of the hardware design. The three conditioned analog outputs from the sensing circuitry are connected to ADC-capable microcontroller pins and are sampled at 100 kHz per channel. This sampling rate was selected to support detection of optical flicker throughout the target 3–60 Hz range. For a maximum signal frequency of

$$f_{\max} = 60\text{Hz},$$

the Nyquist criterion requires

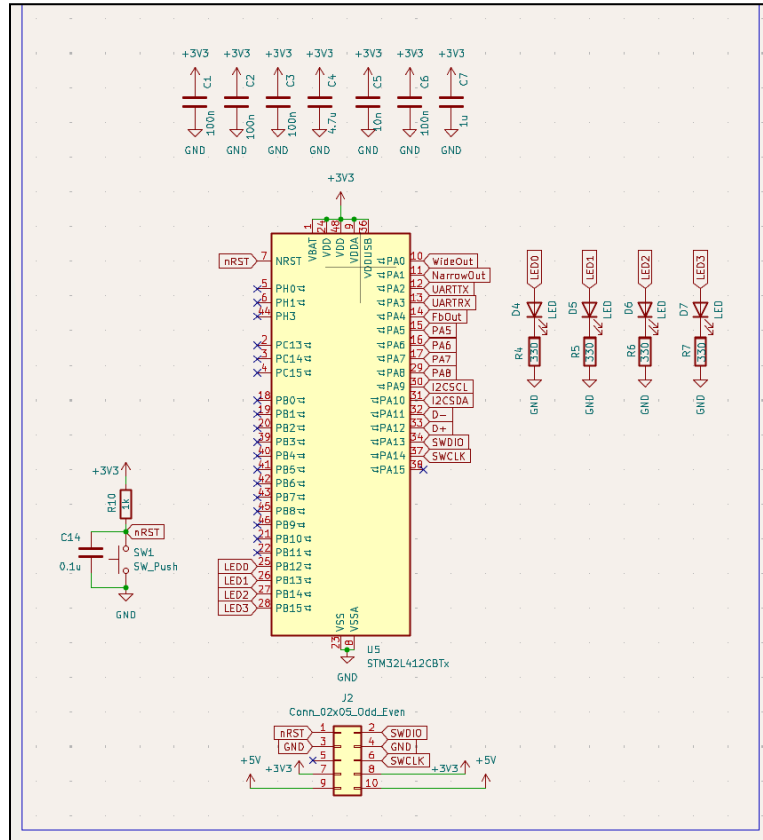
$$f_s > 2f_{\max} = 120\text{Hz}.$$

The selected sampling frequency of 100 kHz therefore exceeds the minimum Nyquist sampling frequency by a factor of approximately

$$\frac{1000000}{120} = 833.33.$$

This also addresses a limitation identified in the EpilepSee prototype, whose 40 Hz light-sensor sampling rate prevented reliable detection of flicker above 20 Hz [2].

The microcontroller communicates with the DAC circuitry through an I<sup>2</sup>C interface. Decoupling capacitors are placed adjacent to the microcontroller supply pins to reduce supply disturbances caused by digital switching. The PCB also includes a programming/debug interface to permit firmware programming and debugging during development.



**Figure 11:** STM32 Microcontroller, Decoupling, and Programming Circuitry [MCU BOX]

### 2.4.3. DAC and TN Light-Valve Drive

The optical attenuation circuitry uses DAC60502 dual-channel DACs [8] to generate the voltages required to control the TN liquid crystal light valves. The DACs receive attenuation commands from the STM32 through the shared I<sup>2</sup>C bus and are powered from the 5 V rail.

Each light valve is connected between two independently controlled DAC outputs. Rather than applying a constant DC voltage across the liquid crystal, the two outputs are periodically exchanged such that

$$V_{LC} = V_{OUTA} - V_{OUTB}.$$

For example, the two drive states may be represented as

$$(V_{OUTA}, V_{OUTB}) = (V_D, 0)$$

$$(V_{OUTA}, V_{OUTB}) = (0, V_D),$$

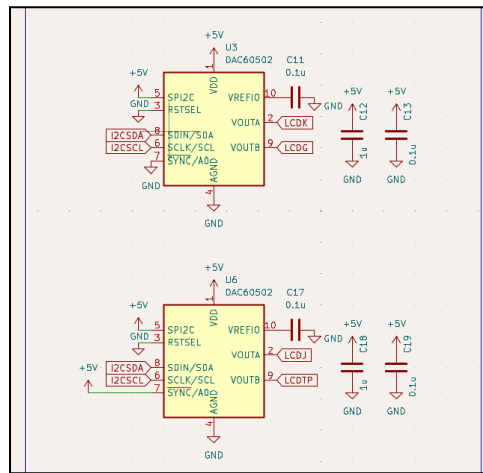
producing

$$V_{LC} = +V_D$$

$$V_{LC} = -V_D,$$

respectively. Alternating between these states with approximately equal duration produces a differential AC excitation with approximately zero average DC voltage across the light valve. This driving method is used because sustained DC bias can degrade TN liquid crystal shutters [10].

Two DAC devices are included to provide the output channels required for controlling the two light valves. VREF and supply decoupling capacitors are placed adjacent to each DAC as recommended by the device implementation requirements [8].



**Figure 12:** DAC and Differential TN Light-Valve Drive Circuit [DAC Box]

#### 2.4.4. Power Regulation

The PCB is powered from an external 5 V USB-C power source. The 5 V rail is used directly by circuitry requiring the higher supply voltage, including the DAC/optical drive circuitry. A TLV73333 3.3 V LDO regulates the 5 V input to provide the 3.3 V rail used by the STM32 and analog sensing circuitry. For a linear regulator, the approximate conversion efficiency can be estimated as

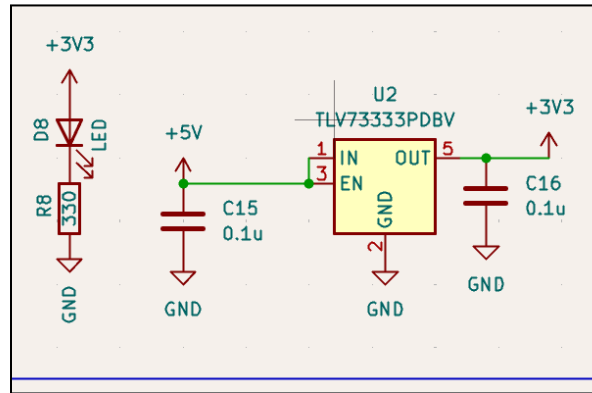
$$\eta \approx \frac{V_{OUT}}{V_{IN}},$$

giving

$$\eta \approx \frac{3.3}{5.0} = 0.66$$

or approximately **66%**, neglecting the regulator's quiescent current. Although a switching regulator could provide greater conversion efficiency, the 3.3 V rail supplies relatively low-power circuitry and the energy source is an external power bank. The LDO therefore provides a simpler regulation architecture while avoiding switching noise near the analog photodiode circuitry.

Input and output capacitors are placed around the regulator to provide local energy storage and maintain stable operation.



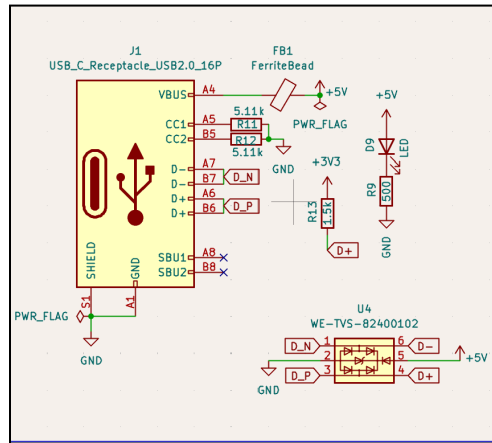
**Figure 13:** 5 V Input and 3.3 Regulation Circuit [POWER]

#### 2.4.5. USB-C, Protection, and External Connections

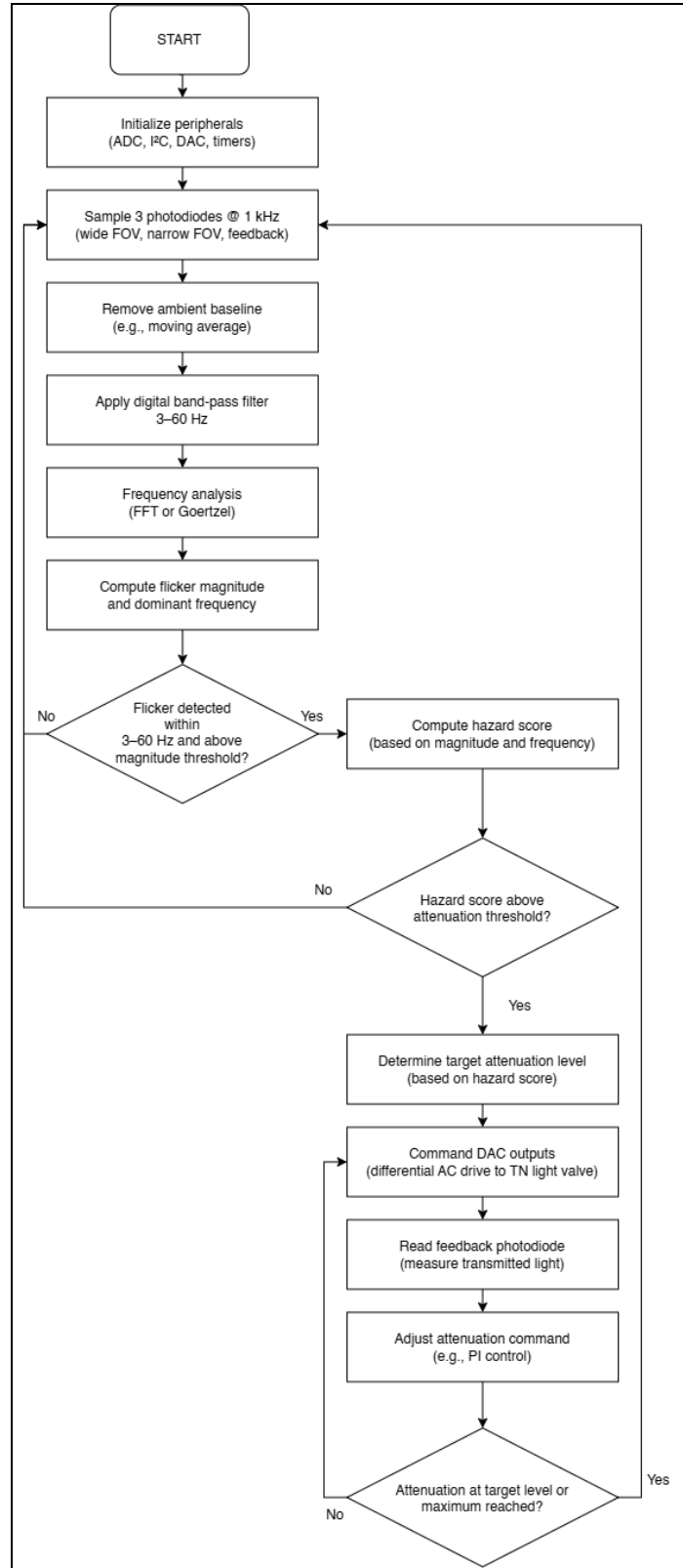
The USB-C interface provides the external 5 V supply connection to the PCB. The USB input includes protection and filtering components before the supply is distributed to the remainder of the system. The USB data lines are not required for normal operation of the glasses unless they are used for programming or debugging.

External connectors provide interfaces between the PCB and components mounted on the wearable assembly. These connections include the three remotely positioned photodiodes and the two TN light

valves. Additional headers expose programming/debug and communication signals required during development. All external connections share the PCB ground reference.



**Figure 14:** USB-C Input, Protection, and External I/O Connections [USB]



**Figure 15:** Software Flowchart for Light Sensing, Flicker Detection, and Adaptive Attenuation Control

## 2.5 Software Design

The software running on the STM32 microcontroller is responsible for acquiring the conditioned photodiode signals, processing the sampled data to identify potentially hazardous flicker, determining the required optical attenuation level, and commanding the DAC outputs that drive the TN liquid crystal light valves. The software also processes the feedback photodiode measurement to evaluate the resulting transmitted light intensity and adjust the attenuation command.

The software is divided into three primary functions: sensor acquisition and signal processing, flicker detection and hazard evaluation, and optical attenuation control. Figure 15 shows the overall software flow.

### 2.5.1 Sensor Sampling and Signal Processing

The STM32 samples the conditioned outputs of the wide-FOV, narrow-FOV, and feedback photodiodes using its ADC. Each channel is sampled at a rate of 100 kHz, producing discrete-time measurements of the incident and transmitted light intensity.

The 100 kHz sampling frequency was selected to provide sufficient temporal resolution for detecting flicker throughout the target 3–60 Hz frequency range. According to the Nyquist sampling criterion, a 60 Hz signal requires a sampling frequency greater than

$$f_s > 2f_{\max} = 120\text{Hz}.$$

Therefore, the 100 kHz sampling frequency provides substantial margin above the minimum required sampling rate. This also addresses a limitation of the EpilepSee proof-of-concept [2], whose 40 Hz light sensor was unable to reliably detect flicker above 20 Hz.

The sampled wide-FOV and narrow-FOV signals are digitally processed before flicker detection. A slowly varying baseline component corresponding to the average ambient illumination is removed so that the algorithm responds primarily to temporal variations in light intensity rather than the absolute brightness of the environment. The resulting signal is digitally filtered to isolate variations within the target 3–60 Hz range and suppress components outside the frequencies relevant to the flicker-detection algorithm.

Processing the signal relative to its ambient baseline also avoids relying on a single fixed absolute-light threshold. This is important because the same absolute change in light intensity can represent substantially different changes under different ambient lighting conditions. The EpilepSee authors similarly identify their use of a fixed 100-lux detection threshold as a limitation under varying real-world lighting conditions [2].

### 2.5.2. Flicker Detection and Hazard Evaluation

After signal conditioning, the software analyzes the wide-FOV and narrow-FOV measurements to determine whether periodic variations in incident light fall within the target **3–60 Hz** frequency range.

Frequency-domain analysis using an FFT or selected-frequency analysis using the Goertzel algorithm will be performed over a sliding window of recent ADC samples.

For each processing window, the algorithm estimates the dominant flicker frequency and the magnitude of the periodic component. Flicker components outside the 3–60 Hz target range are rejected. For signals within this range, the measured magnitude is used to calculate a hazard score representing the strength of the detected flicker.

The wide-FOV and narrow-FOV measurements provide complementary information. The wide-FOV channel measures general variations in the user's surrounding illumination, while the narrow-FOV channel emphasizes light originating approximately in the user's forward field of view. The software evaluates these measurements to distinguish relevant directional flicker from broader changes in ambient illumination.

The detection algorithm produces one of two primary classifications:

- **SAFE:** No flicker satisfying the hazardous-frequency and magnitude criteria is detected. The optical attenuation command remains at its minimum level.
- **HAZARDOUS:** Flicker satisfying the detection criteria is present within the 3–60 Hz range. The attenuation controller increases the commanded optical attenuation.

The complete detection and attenuation process must initiate optical attenuation within **500 ms** of the onset of a qualifying hazardous flicker in order to satisfy the system-level response-time requirement.

### 2.5.3 Optical Attenuation Control

When hazardous flicker is detected, the software determines the attenuation command sent to the DAC60502 devices over I<sup>2</sup>C. Unlike a binary transparent/opaque system, the proposed controller is designed to support multiple attenuation levels. The commanded drive amplitude can therefore be increased or decreased according to the detected flicker magnitude.

For a commanded differential drive magnitude  $V_D$ , the two DAC outputs associated with a light valve alternate between

$$(V_A, V_B) = (V_D, 0)$$

and

$$(V_A, V_B) = (0, V_D).$$

The resulting differential light-valve voltage alternates between

$$V_{LC} = + V_D$$

and

$$V_{LC} = -V_D.$$

The software alternates these states with approximately equal durations to minimize the average DC voltage applied across the TN liquid crystal while maintaining the required RMS drive voltage.

The attenuation command is bounded between a minimum and maximum drive level so that software cannot request a DAC output outside the designed electrical operating range. When no hazardous flicker is detected, the controller returns toward the minimum-attenuation state so that unnecessary reduction of the user's vision is avoided.

This variable attenuation strategy also addresses a limitation identified in previous work. The EpilepSee prototype used a PDLC film that transitioned between transparent and opaque states and achieved only an additional approximately 8% reduction in measured transmitted light after actuation in its preliminary experiment. EpilepSee\_Glasses\_A\_Wearable\_Se... The proposed system instead allows the optical drive level to be adjusted electronically rather than relying solely on binary optical states.

#### **2.5.4 Feedback Control**

The feedback photodiode provides the software with a measurement of the light intensity transmitted through the optical attenuation system. After commanding a new attenuation level, the STM32 samples the feedback photodiode and compares the measured transmitted-light response with the expected direction of change.

If increased attenuation is commanded, the feedback measurement should indicate a corresponding reduction in transmitted light. The controller can use this measurement to incrementally adjust the DAC command until the desired attenuation response is achieved or the maximum permitted drive level is reached.

This feedback mechanism also allows the software to identify abnormal actuator behavior. For example, if the controller substantially increases the attenuation command but the feedback photodiode does not detect the expected change in transmitted light, the system can identify that the commanded optical response may not have occurred rather than assuming successful attenuation.

The control loop must operate without violating the overall 500 ms detection-to-attenuation requirement. Consequently, signal acquisition, flicker analysis, hazard classification, DAC communication, and optical response must collectively occur within this interval.

#### **2.6 Tolerance Analysis**

One of the major risks in the Sensor and Processing Subsystems is the presence of frequency components outside the 3–60 Hz flicker detection band. High-frequency components reaching the ADC can introduce noise or alias into lower frequencies during sampling. The analog front end must therefore preserve the 3–60 Hz flicker band while attenuating higher-frequency signals before digital processing. The sensor outputs are sampled by the microcontroller ADC at approximately

$$f_s = 100kHz$$

According to the Nyquist sampling criterion, the corresponding Nyquist frequency is

$$f_N = \frac{f_s}{2} = 50kHz$$

The high sampling rate provides significant separation between the highest frequency of interest, 60 Hz, and the Nyquist frequency. This reduces the required sharpness of the analog anti-aliasing filter and allows additional filtering to be performed digitally by the Processing Subsystem. The analog front end uses an active low-pass filter with

$$R_1 = R_2 = 16k\Omega$$

$$C_1 = C_2 = 10nF$$

The characteristic frequency of the filter is

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

Substituting the selected component values gives

$$f_0 = \frac{1}{2\pi\sqrt{(16 \times 10^3)^2 (10 \times 10^{-9})^2}} \approx 995Hz$$

The characteristic frequency is significantly greater than the maximum flicker frequency of 60 Hz. Therefore, the 3–60 Hz frequency range is preserved by the analog front end while frequencies substantially above the required detection band are attenuated. For frequencies sufficiently above the characteristic frequency, the second-order low-pass filter approaches a roll-off of approximately 40 dB per decade. The ratio between the selected 10 kHz high-frequency test signal and the filter characteristic frequency is

$$\frac{10kHz}{995Hz} \approx 10.05$$

Since 10 kHz is approximately one decade above the characteristic frequency, the expected high-frequency attenuation is approximately

$$A_{10kHz} \approx -40 \log_{10} \left( \frac{10000}{995} \right) \approx -40.1dB.$$

In comparison, 60 Hz is significantly below the characteristic frequency,

$$\frac{60}{995} \approx 0.0603,$$

and therefore experiences minimal attenuation. The analog front end is consequently expected to provide approximately 40 dB of additional attenuation at 10 kHz compared with the 60 Hz upper edge of the flicker detection band. A 40 dB reduction in voltage amplitude corresponds to an amplitude ratio of

$$\frac{V_{out,10kHz}}{V_{out,60Hz}} = 10^{-40/20} \approx 0.01.$$

Therefore, an equal-amplitude 10 kHz input is expected to produce an output approximately 1% of the amplitude produced by a 60 Hz input. Following ADC conversion, hardware oversampling and digital filtering in the Processing Subsystem provide additional noise reduction and frequency selection. Component tolerances can cause the actual filter characteristic frequency to vary from its nominal value. Assuming  $\pm 1\%$  tolerance for the resistors and  $\pm 5\%$  tolerance for the capacitors, the minimum expected characteristic frequency occurs when both resistance and capacitance are at their maximum values:

$$f_{0, \min} = \frac{995}{(1.01)(1.05)} \approx 938Hz.$$

Similarly, the maximum expected characteristic frequency occurs when both resistance and capacitance are at their minimum values:

$$f_{0, \max} = \frac{995}{(0.99)(0.95)} \approx 1058Hz.$$

Thus, the expected characteristic frequency lies within the range

$$938Hz \leq f_0 \leq 1058Hz.$$

Even under the worst-case component tolerances, 60 Hz remains significantly below the analog filter characteristic frequency, while 10 kHz remains approximately one decade above it. Therefore, variations in the resistor and capacitor values do not significantly affect preservation of the 3–60 Hz flicker detection band or the attenuation of higher-frequency components before ADC sampling.

### 3. Cost and Schedule

#### 3.1 Cost Analysis

##### 3.1.1 Cost Analysis - Labor

The labor cost is estimated using the average starting salary of a University of Illinois Computer Engineering graduate. According to the University of Illinois Department of Electrical and Computer Engineering, the average starting salary for a Computer Engineering graduate during the 2024–2025 academic year was \$119,064 [10]. Assuming 40 working hours per week and 52 weeks per year, this corresponds to an hourly wage of approximately \$57.24/hour.

Each team member is estimated to spend approximately 150 hours designing, assembling, programming, testing, and documenting the project over the course of the semester. Following the required 2.5× labor-cost multiplier, the estimated labor cost per team member is:

Labor Cost per Team Member:

$$\begin{aligned} &= (\$57.24/\text{hour})(2.5)(150 \text{ hours}) \\ &= \$21,465.00 \end{aligned}$$

For two team members:

$$\begin{aligned} &= 2(\$21,465.00) \\ &= \$42,930.00 \end{aligned}$$

##### 3.1.2 Cost Analysis - Parts

Table 5 lists the electronic components currently required to construct one complete system. Component prices are based on the selected parts in the project parts list and represent estimated unit prices at the time of preparation of this design document. Spare components ordered for fabrication and debugging are not included in the project cost calculation because they are not required in the final assembled device. Additional mechanical components and fabrication costs that have not yet been finalized are listed separately as TBD.

| Description                     | Manufacturer      | Part #        | Quantity | Unit Cost | Total   | Link                 |
|---------------------------------|-------------------|---------------|----------|-----------|---------|----------------------|
| Quad RRIO Operational Amplifier | Texas Instruments | TLV9064IDR*   | 4        | \$1.73    | \$6.92  | <a href="#">Link</a> |
| 3.3 V LDO Regulator             | Texas Instruments | TLV73333PDBVR | 1        | \$0.17    | \$0.17  | <a href="#">Link</a> |
| Dual 12-bit DAC                 | Texas Instruments | DAC60502DRXR  | 2        | \$6.65    | \$13.30 | <a href="#">Link</a> |

|                               |                             |                     |    |        |        |                      |
|-------------------------------|-----------------------------|---------------------|----|--------|--------|----------------------|
| USB ESD/TVS Protection Array  | Würth Elektronik            | 82400102            | 1  | \$0.86 | \$0.86 | <a href="#">Link</a> |
| Microcontroller               | STMicroelectronics          | STM32L412CBT6       | 1  | \$4.77 | \$4.77 | <a href="#">Link</a> |
| USB-C Receptacle              | GCT                         | USB4085-03-A        | 1  | \$1.50 | \$1.50 | <a href="#">Link</a> |
| Tactile Switch                | Alps Alpine                 | SKRKAEE010          | 1  | \$0.55 | \$0.55 | <a href="#">Link</a> |
| Ferrite Bead                  | Murata                      | BLM21PG221SN1D      | 1  | \$0.10 | \$0.10 | <a href="#">Link</a> |
| Silicon PIN Photodiode        | Vishay                      | BPW34               | 3  | \$1.50 | \$4.50 | <a href="#">Link</a> |
| 0805 Red Indicator LED        | Kingbright                  | APT2012SURCK        | 6  | \$0.12 | \$0.72 | <a href="#">Link</a> |
| 47 k $\Omega$ 0805 Resistor   | Yageo                       | RC0805FR-0747KL     | 3  | \$0.03 | \$0.09 | <a href="#">Link</a> |
| 330 $\Omega$ 0805 Resistor    | Yageo                       | RC0805FR-07330RL    | 5  | \$0.03 | \$0.15 | <a href="#">Link</a> |
| 500 $\Omega$ 0805 Resistor    | Yageo                       | RC0805FR-07500RL    | 1  | \$0.03 | \$0.03 | <a href="#">Link</a> |
| 1 k $\Omega$ 0805 Resistor    | Yageo                       | RC0805FR-071KL      | 1  | \$0.03 | \$0.03 | <a href="#">Link</a> |
| 5.11 k $\Omega$ 0805 Resistor | Yageo                       | RC0805FR-075K11L    | 2  | \$0.03 | \$0.06 | <a href="#">Link</a> |
| 1.5 k $\Omega$ 0805 Resistor  | Yageo                       | RC0805FR-071K5L     | 1  | \$0.03 | \$0.03 | <a href="#">Link</a> |
| 0.1 $\mu$ F 0805 Capacitor    | Kemet                       | C0805C104K5RAC AUTO | 11 | \$0.04 | \$0.44 | <a href="#">Link</a> |
| 1 $\mu$ F 0805 Capacitor      | Murata                      | GRM21BR71C105KA01L  | 3  | \$0.06 | \$0.18 | <a href="#">Link</a> |
| 4.7 $\mu$ F 0805 Capacitor    | Murata                      | GRM21BR61A475KA73L  | 1  | \$0.12 | \$0.12 | <a href="#">Link</a> |
| 10 nF 0805 Capacitor          | Kemet                       | C0805C103K5RAC TU   | 1  | \$0.03 | \$0.03 | <a href="#">Link</a> |
| 2×5 Female Header             | Sullins Connector Solutions | PPTC102LFBN-RC      | 1  | \$0.80 | \$0.80 | <a href="#">Link</a> |

|                                              |                             |                       |                     |        |        |                      |
|----------------------------------------------|-----------------------------|-----------------------|---------------------|--------|--------|----------------------|
| 1×4 Female Header                            | Sullins Connector Solutions | PPTC041LFBN-RC        | 2                   | \$0.30 | \$0.60 | <a href="#">Link</a> |
| 1×3 Female Header                            | Sullins Connector Solutions | PPTC031LFBN-RC        | 2                   | \$0.25 | \$0.50 | <a href="#">Link</a> |
| 1×2 Female Header                            | Sullins Connector Solutions | PPTC021LFBN-RC        | 5                   | \$0.20 | \$1.00 | <a href="#">Link</a> |
| M3 Mounting Hardware                         | TBD                         | M3 Screw/Standoff Set | 4                   | \$0.25 | \$1.00 | <a href="#">Link</a> |
| TN Liquid Crystal Light Valve                | TBD                         | TBD                   | 2                   | TBD    | TBD    |                      |
| Wearable Glasses Frame / Adjustable Headband | TBD                         | TBD                   | 1                   | TBD    | TBD    |                      |
| Portable Power Pack                          | TBD                         | TBD                   | 1                   | TBD    | TBD    |                      |
| Custom PCB Fabrication                       | TBD                         | Custom PCB            | 1                   | TBD    | TBD    |                      |
| PCB / Electronics Enclosure                  | TBD                         | Custom                | 1                   | TBD    | TBD    |                      |
| Wiring, Connectors, and Cabling              | TBD                         | TBD                   | 1 set               | TBD    | TBD    |                      |
| Current Total                                |                             |                       | \$33.26 + TBD Costs |        |        |                      |

**Table 5: Current Electronic Component Costs**

### 3.1.3 Cost Analysis - Total Cost

Based on the components that have currently been selected, the electronic components required for one complete system have an estimated cost of \$33.26. This value does not yet include the TN liquid crystal light valves, wearable frame, portable power source, PCB fabrication, enclosure fabrication, or miscellaneous wiring and mechanical materials because these components have not yet been finalized.

Current Parts Cost = \$33.26

Estimated Labor Cost = \$42,930.00

Current Estimated Project Cost

$$= \$33.26 + \$42,930.00$$

$$= \$42,963.26$$

The final project cost will be updated once the remaining optical, mechanical, power, and fabrication components have been selected and their costs are known. No specialized external laboratory equipment or paid machine-shop services are currently anticipated; standard ECE laboratory equipment and fabrication resources will be used where available.

### 3.2. Schedule

The below table presents the expected sequence of design, fabrication, integration, and testing activities for the remainder of the project. The schedule is aligned with the major ECE 445 course milestones, including the Design Review, Breadboard Demo, Progress Demo, Mock Demo, and Final Demo. Responsibilities are divided between the two team members according to subsystem ownership, with system integration, testing, and final demonstration activities completed collaboratively.

| Week | Dates               | Expected Design / Construction Work                                                                    | Kewal                                                                  | Jahnavi                                                                        |
|------|---------------------|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 1-3  | Aug. 24 – Sept. 11  | Define problem, select system architecture, research components, and obtain project approval           | Research optical attenuation, power, and physical implementation       | Research sensing, flicker detection, and processing architecture               |
| 4-5  | Sept. 14 – Sept. 25 | Finalize subsystem designs, select components, begin schematics, and prepare initial mechanical design | Develop optical attenuation/power circuitry and physical layout        | Develop photodiode/TIA and processing circuitry                                |
| 6    | Sept. 28 – Oct. 2   | Complete PCB schematic/layout, PCB review, Design Document, cost analysis, and mechanical design       | Review optical/power circuitry, footprints, and mechanical integration | Review sensor/processing circuitry, footprints, and PCB interfaces             |
| 7    | Oct. 5 – Oct. 9     | Complete Design Review, incorporate feedback, finalize PCB, and order components/PCB                   | Revise optical/power design based on review                            | Revise sensor/processing design based on review                                |
| 8    | Oct. 12 – Oct. 16   | Demonstrate subsystem concepts on breadboard; complete any necessary PCB revisions; begin firmware     | Breadboard-test DAC/light-valve and power circuitry                    | Breadboard-test photodiode/TIA circuitry and begin sampling/detection firmware |

|    |                   |                                                                                                 |                                                                        |                                                                                                |
|----|-------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| 9  | Oct. 19 – Oct. 23 | Assemble received hardware and independently test PCB subsystems                                | Assemble/debug power and optical attenuation circuitry                 | Assemble/debug sensor and processing circuitry                                                 |
| 10 | Oct. 26 – Oct. 30 | Complete PCB debugging and final PCB revision if necessary; begin mechanical prototype assembly | Debug optical drive and integrate PCB/enclosure hardware               | Debug sensor acquisition and flicker-detection software                                        |
| 11 | Nov. 2 – Nov. 6   | Progress Demo: demonstrate working subsystems and begin full-system integration                 | Integrate optical attenuation hardware with MCU control                | Integrate sensor subsystem and flicker-detection algorithm with MCU                            |
| 12 | Nov. 9 – Nov. 13  | Integrate complete wearable prototype and implement optical feedback control                    | Assemble light valves, PCB, power, and wearable hardware               | Install/position photodiodes and integrate closed-loop sensing                                 |
| 13 | Nov. 16 – Nov. 20 | Mock Demo: complete integrated prototype; identify and correct remaining problems               | Refine hardware, optical attenuation, and mechanical assembly          | Refine detection algorithm, feedback control, and system response                              |
| 14 | Nov. 23 – Nov. 27 | Fall Break; perform limited debugging/documentation as needed                                   | Documentation/data review as needed                                    | Documentation/data review as needed                                                            |
| 15 | Nov. 30 – Dec. 4  | Final Demo and Presentation: perform final R&V testing and demonstrate completed system         | Conduct power, optical, and endurance verification; support final demo | Conduct detection accuracy, false-positive, and response-time verification; support final demo |
| 16 | Dec. 7 – Dec. 10  | Complete final paper, lab notebook, and lab checkout                                            | Complete assigned final documentation and notebook                     | Complete assigned final documentation and notebook                                             |

**Table 6:** *Timeline of the rest of the semester*

## 4. Discussion of Societal Impact, Engineering Standards, Ethics, and Safety Considerations

### Societal Standpoint:

The adaptive light-filtering glasses are intended to make a positive contribution to public health, safety, and welfare by investigating a wearable method for reducing a user's exposure to potentially hazardous flickering light. Individuals with photosensitive conditions may encounter flickering visual stimuli from displays, artificial lighting, entertainment, and other sources that cannot always be predicted or avoided. The proposed system attempts to address this problem by detecting flicker in real time and automatically controlling an optical light valve rather than requiring the user to identify and respond to the stimulus manually. However, the prototype is an engineering proof of concept and will not be represented as a clinically validated medical device or as a means of preventing seizures.

The design also has economic, environmental, social, and global considerations. Economically, the system is constructed primarily from commercially available electronic and optical components with the goal of demonstrating the concept without specialized medical equipment. A wearable implementation could also allow the system to be used across multiple environments rather than modifying individual displays or light sources. Environmentally, the design uses rechargeable power rather than disposable batteries, although the battery, PCB, and electronic components contribute to electronic waste and should be disposed of or recycled appropriately at the end of their useful life. Socially, a wearable device may provide greater independence when encountering unpredictable visual environments, although comfort, appearance, accessibility, and potential stigma associated with wearing visible assistive technology must be considered. The underlying problem is not limited to a particular geographic region; therefore, a portable design based on broadly available components could potentially be adapted to different environments and populations. These potential benefits do not establish clinical effectiveness, which remains outside the scope of this project.

### Applicable Engineering Standards:

Several engineering standards provide relevant safety guidance for the electrical, battery-powered, and optical aspects of the prototype. **IEC 62133-2:2017+A1:2021** specifies safety requirements and tests for portable rechargeable lithium cells and batteries under intended use and reasonably foreseeable misuse, making it relevant to the rechargeable battery used by the wearable system [5]. **IEC 62368-1:2023** establishes a hazard-based framework for identifying energy sources in electronic equipment and providing appropriate safeguards against injury or fire; its principles are relevant to the low-voltage electronics, enclosure, and power subsystem of the prototype [4].

Optical safety is also considered because the prototype interacts directly with the user's visual field and because controlled light sources may be used during testing. **IEC 62471:2006** establishes exposure limits, measurement techniques, and classifications for evaluating photobiological hazards associated with electrically powered optical radiation sources [10]. The prototype itself does not generate the hazardous environmental light that it is intended to detect; nevertheless, the principles of IEC 62471 are relevant when selecting and operating artificial light sources used to generate controlled optical test inputs.

Compliance with these standards is not being claimed. Instead, the standards are used as engineering references for identifying hazards and developing appropriate safety procedures for the prototype.

#### 4.3: Ethics:

The primary ethical concern associated with the adaptive light-filtering glasses is the possibility that experimental engineering performance could be incorrectly interpreted as evidence of medical effectiveness. Successful detection and attenuation of flickering light does not demonstrate that the glasses prevent seizures or provide clinically effective protection to individuals with photosensitive epilepsy. Consistent with the IEEE Code of Ethics, technical claims regarding the prototype will therefore be limited to quantities that can be experimentally verified, including flicker-detection accuracy, false-positive rate, response time, optical attenuation, and battery life. The prototype will not be described as diagnosing, treating, or preventing a medical condition.

The project also relates directly to the IEEE ethical responsibilities concerning public safety, understanding the implications of technology, making honest and realistic technical claims, and working within areas of technical competence. Because the device directly modifies the user's vision, unexpected attenuation or system failure could affect the safety of both the wearer and surrounding individuals. The intended use, operating conditions, limitations, and known failure modes of the prototype will therefore be explicitly documented.

Testing involving potentially hazardous flickering light introduces an additional ethical concern. Individuals with known photosensitivity will not be intentionally exposed to hazardous flickering stimuli for the purpose of evaluating the prototype. Detection testing will instead use photodiodes, instrumentation, cameras where appropriate, and controlled artificial optical inputs. This allows the engineering performance of the system to be characterized without requiring exposure of a vulnerable human subject.

Potential misuse must also be considered. A user could incorrectly treat the prototype as medically validated protection and intentionally expose themselves to stimuli that they would otherwise avoid. A user could similarly operate the glasses while driving, cycling, walking near traffic, or performing another activity in which unexpected attenuation could create a hazard. These applications will be explicitly identified as outside the intended operating conditions of the prototype.

#### 4.4: Electrical and Mechanical Safety:

The power subsystem introduces electrical and thermal hazards associated with rechargeable lithium batteries, including short circuits, overcurrent, physical damage, improper charging, and overheating. To reduce the consequences of a battery failure near the user's face or head, the rechargeable power source is physically separated from the glasses and located in an external clippable power pack. Battery charging will only be performed using the intended charging hardware, and damaged, swollen, punctured, or abnormally hot batteries will not be used. Exposed conductors and PCB connections will be electrically insulated before the integrated system is worn.

The wearable structure introduces mechanical hazards that were less developed at the proposal stage. The PCB, wiring, photodiodes, light valves, and mounting hardware must be secured so that components

cannot detach during normal movement. Sharp PCB edges, solder joints, component leads, and exposed wiring must not contact the user's skin. The rear PCB enclosure and front optical assembly will therefore use protective enclosures or insulating material, and the headband will be adjusted so that the device can be worn without excessive pressure on the head, nose, or face.

The optical attenuation system introduces a separate functional safety concern. A false-positive detection or hardware/software malfunction could cause the light valves to attenuate unexpectedly and temporarily reduce the user's visibility. Testing while the glasses are worn will therefore only occur in a stationary, controlled indoor environment without traffic, stairs, machinery, or other hazards requiring unobstructed vision. The prototype is not intended for use while driving, cycling, operating machinery, or navigating near traffic.

#### 4.5: Safety Mitigation Procedures:

The following procedures will be followed during fabrication, testing, integration, and demonstration of the prototype:

| <b>Hazard</b>                                | <b>Mitigation Procedure</b>                                                                                                                                                                                                                                                                     |
|----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rechargeable battery failure                 | Inspect the battery/power pack before use and discontinue use if swelling, puncture, excessive heating, or other physical damage is observed. Charge only using the intended charging system and do not leave experimental charging configurations unattended.                                  |
| Electrical short circuit / overheating       | Verify power rails and check for shorts before connecting the complete system. Initial PCB power-up will be performed using a current-limited laboratory supply where practical. Power will immediately be disconnected if excessive current, heating, smoke, or abnormal behavior is observed. |
| Exposed PCB/electrical connections           | Electrically insulate exposed conductors and place the PCB in its enclosure before wearable testing. No exposed solder joints or component leads will be permitted to contact the wearer.                                                                                                       |
| Unexpected light-valve attenuation           | First verify attenuation behavior without wearing the device. Wearable testing will only occur while stationary in a controlled indoor environment. The glasses will not be tested while driving, cycling, operating machinery, using stairs, or near traffic.                                  |
| Potentially hazardous flicker during testing | Use electronic instrumentation and photodiodes as the primary means of evaluating flicker detection. Individuals with known photosensitivity will not be intentionally exposed to hazardous flickering                                                                                          |

|                                 |                                                                                                                                                                                |
|---------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| stimuli as test subjects.       |                                                                                                                                                                                |
| Mechanical component detachment | Inspect the frame, PCB enclosure, light valves, sensors, wiring, and mounting hardware before wearable testing. Loose components must be secured before the prototype is worn. |
| Sharp edges/components          | Enclose PCB edges and soldered components and use insulating/protective material at locations that could contact the user's skin.                                              |
| Device malfunction while worn   | Remove or power off the device immediately if unexpected heating, repeated unintended attenuation, unstable behavior, loose components, or other abnormal operation occurs.    |

These procedures are intended to protect both developers and users throughout construction and testing. The project operates at low electrical voltages and does not contain high-voltage, high-power, chemical, or aerial systems requiring a separate high-risk Safety Manual. Nevertheless, because the prototype contains a rechargeable battery, is physically worn by a person, modifies the user's field of view, and is associated with a photosensitive population, battery, wearable, optical, and human-interface safety will be treated as explicit design constraints throughout development.

## 4. Citations

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